Efficiency Improvement of Lattice Map Generation for Simulating the Spread of Fire by Electronic Housing Map

Mengchun Xie*[1], Hideyuki Noguchi[2]

[1]Department of Electrical and Computer Engineering, Wakayama National College of Technology
Noshima 77, Nada-Cho, Gobo City, Wakayama, Japan

[2]Dai Nippon Printing Co., Ltd., Okubaracho, Ushiku, Ibaraki, Japan

*[1]xie@wakayama-nct.ac.jp; [2]noguchi-h10@mail.dnp.co.jp

Abstract

Forecasting the spread of fire in the aftermath of an earthquake by simulation is useful for prompt fire fighting and selection of resident evacuation routes. A simulation system has been developed using Cellular Automata (CA). The map data of the simulated region is necessary to forecast a fire by CA. This research introduces an electronic housing map into the fire simulation system for improving the lattice-map-generation process. In the system designed in this study, a lattice map can be prepared by reading the color information of the buildings as soon as a region is specified. This process has greatly shortened the time to create the lattice map and simulates accurate shapes of the buildings. Moreover, a method is proposed to arrange cells suitable for the urban districts of the Gobo-Hidaka area, in which a fire is simulated.

Keywords

Lattice-map-generation; Simulation; Electronal Housing Map; Cellular Automata; Spread of Fire

Introduction

The probability for the occurrence like Tonankai and Nankai earthquake is high, which is attributed to the higher ratio of wooden houses compared to that in other areas. However, it is difficult to predict a potential region, that is, where an evacuation route is limited by the collapse of buildings, fire and the destruction of roads. Research into disaster prevention is required because of the potential for large economic, human and material losses. Therefore, predicting the spread of post-earthquake fire by simulation is useful for extinguishing the fire, selecting the evacuation routes, and reducing the extent of damage caused by fire.

Cellular automata (CA) are arrays of discrete cells with discrete values. Sufficiently large cellular automata often show seemingly continuous macroscopic behavior (Wolfram, 1986). Thus, they can serve as models for continuum systems, such as forest fires, earthquake disasters, road traffic, fluid flows, and so on. In CA, each cell examines the state of neighboring cells, and a simple rule is applied to change the state of a cell depending on the state of its neighboring cells. For the most part, very complicated behavior is exhibited because each cell mutually influences its neighboring cells. Therefore, the overall behavior of a system is well suited to simulate a phenomenon that is complicated and not easily modeled by other simulation methods. Fire in the aftermath of an earthquake is one phenomenon that exhibits such complicated behavior.

Fire simulation by CA is carried out for conditions reflecting the situation directly after an earthquake (Xie *et al*., 2001; Yamada *et al*., 1998; Xie *et al*., 2003). The effectiveness of this method has been confirmed experimentally. However, preparation of the lattice map in a conventional CA fire simulation is a time-consuming manual operation; that is, information about road, house and other buildings for each cell is input by hand, and building shapes cannot be accurately specified. Therefore, in the present study, a method of lattice map generation is proposed by using an electronic housing map to drastically shorten the preparation time of the lattice map and to accurately represent the shapes of buildings. To verify the effectiveness of the proposed method, a simulation is performed for an urban district in the Gobo-Hidaka area, and the simulation results are compared experimentally to those of conventional methods (xie and Kiritoshi, 2006).

Fire Simulation Model by CA

Cellular Automata, discrete space-time models that can be used to model many complex systems(Yu and

Saldana, 2001; Delorme, 1999; Wolfram and Wilhelmson, 1998; Talia, 2002; Xie and Okazaki, 2008), consist of regular discrete lattices of cells. Evolution takes place over a discrete number of timesetps. Each cell is characterized by a state taken from a finite set of states, and this evolves according to a fixed rule that depends only on the state of the cell and a finite number of neighboring cells. The neighborhood relation is local and uniform.

The simulation of the spread of fire using CA is composed of two parts: cell generation, in which cells are generated from a map, and transition of the state of the generated cells (Xie *et al*., 2001). Cell generation is the method by which the urban district is divided into a two-dimensional square lattice. This lattice is called the lattice map, which is made up of individual cells. Each cell corresponds to, for example, a wooden building, a reinforced structure or a road, and each cell takes one of the following six states:

(i) Wooden cell: Wooden building (combustible).

(ii) Fire resistant cell: Fireproof structure (non-combustible).

(iii) Fireproof cell: Fireproof building (does not burn).

(iv) Road cell: Road or vacant land (does not burn).

(v) Combustion cell: Burning building.

(vi) Extinguished cell: Burnt out building (does not burn).

Here, wooden cells and fire resistant cells are referred to as combustible cells because they are both can be burned.

Cells are subject to two types of state transitions. One is transition from a combustible cell to a combustion cell by the probability calculated, corresponding to the spread of fire to a combustion cell. The other is transition from a combustion cell to an extinguished cell, corresponding to the complete combustion of a cell. Road cells, fireproof cells and extinguished cells cannot change state.

The combustion decision determines whether vulnerable cells change into combustion cells, and is probabilistic in nature. The probability p of a vulnerable cell changing to a combustion cell is given by:

$$p=\frac{W_e \cdot C_b \cdot C_f}{C_d} \tag{1}$$

where W_e is the parameter which shows influence of a wind. W_e is calculated as follows:

$$W_e = \begin{cases} \dfrac{W^2}{8}+1 & (W \geq 0) \\ 1 & (W < 0) \end{cases} \tag{2}$$

C_b, the inflammability of the cell in windless circumstances, is dependent on the type of cell ($1 \geq C_b \geq 0$). C_b is calculated as follows (Hayashi and Itoigawa, 2005; Zukoski *et al*., 1981; Sato *et al*., 1999).

Inside Buildings

Wooden cell $C_b = 0.56$

Fire resistant cell $C_b = 0.28$

Between Building

Wooden cell

$$C_b = \frac{V}{92.4} \tag{3}$$
$$V = (1.676 \times e^{0.510L}) \times (0.048U + 0.822)$$

Fire resistant cell

$$C_b = \frac{V}{184.8} \tag{4}$$
$$V = (1.956 \times e^{0.510L}) \times (0.048U + 0.822)$$

where L is the distance between buildings (m), V is the spreading velocity of the fire (m/h), and the U is the wind velocity (m/s).

C_f is the force of the fire of the combustion cell. When the cell is burning most intensely, this becomes C_f =1. C_f is calculated as follows:

$$C_f = \begin{cases} 1-\left(\dfrac{t-7.0}{13.0}\right)^2 & \text{(wooden cell)} \\ 0.7 \cdot \left\{1-\left(\dfrac{t-12.0}{18.0}\right)^2\right\} & \text{(fire resistant cell)} \end{cases} \tag{5}$$

C_d is a parameter that represents the distance between the combustion cell and vulnerable cell. The value of C_d increases as the distance increases ($C_d \geq 1$). W_e, a parameter which represents the effect of wind, is W_e =1 for 0 m/s wind.

Vulnerable cells change to combustion cells, when the following condition is satisfied:

$$p \geq R_f \tag{6}$$

Where R_f is a uniform random number and ($1 \geq R_f \geq 0$). This is calculated for all vulnerable cells.

Efficiency of Lattice Map Generation for CA Simulation

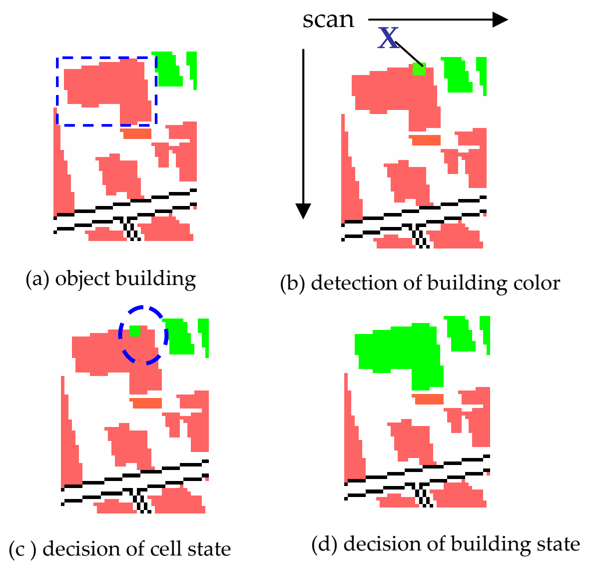
Generation a Lattice Map Using the Electronic Housing Map

Lattice map generation using the electronic housing map consists of two parts: acquisition of color information of the pixels and deciding the state of cells.

The object area of the lattice map on the electronic

housing map is designated, and the color information of the pixel is acquired from the region in a meter four every quarters.

The flowchart for the decision of the state of cells is as follows. First, the selected region is scanned at every pixel according to a decided order. For cells designated by color to be buildings, the state of each cell is randomly determined by the probability due to the ratio of wooden to fire resistantand fireproof buildings. When the color information does not indicate a building, then the cell becomes a road cell. Second, the state of the building is decided. In other words, all cells that belong to the same building are set as one state. For example, in the case of Figure 1(a), the color of the object building is detected at the X point when the object area is scanned from the upper left, and the state of the cell at the X point is decided (Figure 1(b)(c)). The state of other cells in the building indicated by the X point is assumed to be the same as that at the X point (Figure 1(d)). The lattice map is completed by doing this for the entire specified region.



(a) object building (b) detection of building color

(c) decision of cell state (d) decision of building state

FIG. 1 THE DECISION OF CELL STATE FOR A BUILDING

In the preparation of the object area of the lattice map, a building structure is classified into the one of the following three types by investigation of the difference ratio for wooden, fire resistant and fireproof buildings:

Type 1: The major part is wooden housing (the region where wooden housing occupies a majority).

wooden : fire resistant : fireproof = 75 : 20 : 5

Type 2: The major part is newly built housing (the region where many newly built houses exist).

wooden : fire resistant : fireproof = 60 : 33 : 7

Type 3: The major part is vest-pocket housing (the region where multiple dwelling houses exist).

wooden : fire resistant : fireproof = 45 : 45 : 10

In the lattice map preparation, one type is chosen that corresponds to the features of the urban district composition of the region. Moreover, if a building area is extremely large, it is assumed to be a fireproof building.

CA Fire Simulation Using the Electronic Housing Map

The composition of the CA fire simulation using the electronic housing map is shown in Figure 2. The flow from lattice map preparation to fire predictive simulation is shown as follows:

① Click the address search button to display the address retrieval dialog to choose the address in the region for fire prediction. The number corresponding to the number in the main window of the simulation is shown on the right side.

② Click the button on a region and then the center of the region for fire prediction on the electronic housing map. This determines the region for the preparation object of the lattice map.

③ Click the building structure button to display the dialog that assigns the building composition. This sets the building structure as the difference ratio among wooden, fire resistant, fireproof.

④ Make the lattice map.

⑤ Click the Fire CA RUN button to execute the fire forecast simulation.

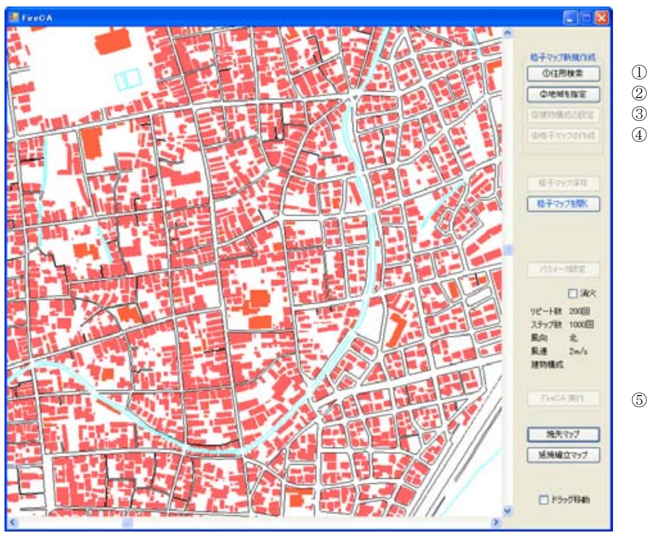
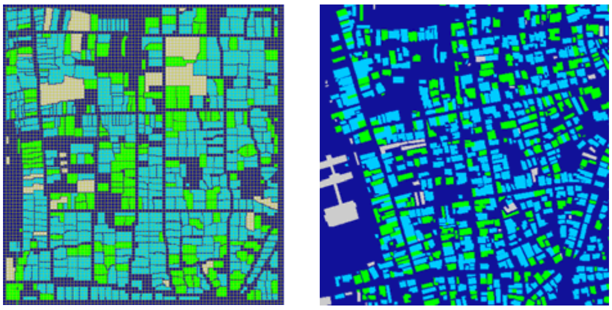


FIG. 2 THE COMPOSITION OF THE CA FIRE SIMULATION USING THE ELECTRONIC HOUSING MAP

Experiment and Discussion

Comparison of Lattice Maps Generated by Different Methods

Figure 3(a) and 3(b) shows the lattice maps generated by the conventional CA method and the improved method using the electronic housing map, respectively.



(a) conventional method (b) improved method

wooden cell fire resistant cell

fireproof cell road cell

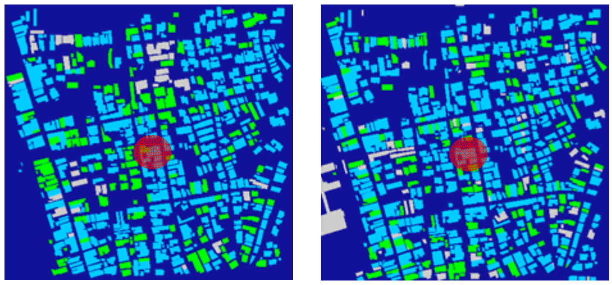
FIG. 3 LATTICE MAPS GENERATED BY CONVENTIONAL AND IMPROVED CA METHODS

The lattice shown in Figure 3(a) contains only wooden cells, fire resistant cells and fireproof cells, but not smaller road cells. Although the open spaces between actual buildings are generally represented as being empty, the conventional method cannot reflect smaller vacant areas, resulting in a large error of cell states.

In Figure 3(b), the improved method represents the vacant land between buildings, and thus reflecting the actual urban district situation very well. Also, the time of generation is very different: for a region 500 m × 500 m, the time cost for the conventional method is approximately one week, but the cost is only one minute for the improved method. However, there are some building structures unlike the actual buildings, because the building structure is randomly set by the ratio.

Experimental Verification of the Set of Building Structures

In this study, when the lattice map is generated, the state of the cell for a building structure is set randomly by the ratio corresponding to the characteristics of the urban district. Consequently, the result of the fire predictive simulation may be different from actual practice. A comparison experiment is carried out to verify the effectiveness of the random setting. In the experiment, three lattice maps are randomly created using the ratio of Type 1. Figure 4(a) shows the state of cells by investigation of the actual field, and Figure 4(b) shows the state of the cells by setting them randomly.



(a) investigation of the field (b) random setting

point of ignition

FIG. 4 VERIFICATION OF RANDOM SETTING OF CELL

The burned cell count is the sum of the combustion cells and extinguished cells. The time profile of the burned cell count, which is the mean value calculated from 200 iterations of the simulation, is shown in Figure 5 which includes all results for cases of the investigation and the three different maps of the random setting. It is demonstrated in Figure 6 that the random setting of the state of cells closely approximates that of the actual investigation in terms of the change in burned cells over time and the slopes of the curved lines. The error after a fire breaks out increases between2 hours and 5 hours. It is considered that the fire progression extension root is changed by the distribution situation of the fireproof buildings. Especially, the fire progression area drastically decreases on Map 1, since many fireproof buildings are distributed around a wide road.

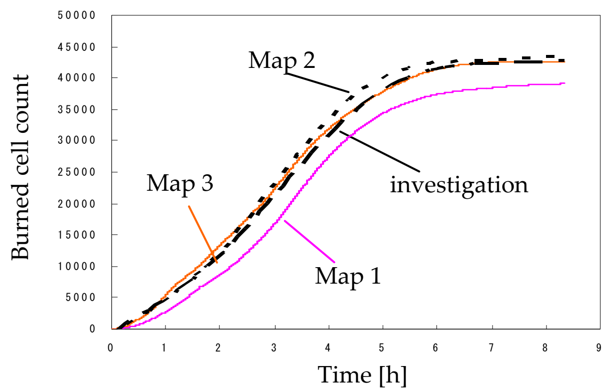


FIG. 5 CHANGE IN BURNED CELL COUNT OVER TIME

The error of the map of the field investigation and the map randomly set is shown in Table 1. The range of error is from -22.4% to 15.5% for field investigation of the biggest gap of the burned cell count. Also, the absolute value of the average error is 12.3% for Map 1, even at the maximum. It can be said that the error does not influence the result of the fire prediction result.

TABLE 1 THE ERROR OF BURNED CELL COUNT USING RANDOM MAP SETTING

	Map1	Map2	Map3
maximum error (%)	-22.4	15.5	9.2
average error (%)	12.3	1.9	4.4

Conclusions

In this study, efficiency improvement of lattice map generation has been examined using an electronic housing map. The color information of every pixel was acquired, and a new lattice map production system of randomly setting the building structures according to three ratios was constructed. As a result, in the comparison with generation of a map using the conventional CA method, the proposed preparation of a lattice map was reduced from one week to only a few minutes, and the new method was able to specify the actual building shape.

A comparison experiment between the proposed method and the field investigation was carried out for the state of the cells of the building structure. Since the fire progression extension root was changed by the distribution of the fireproof buildings, a fire breaking out changed from 2 hours to 5 hours, and the error increased on the random set map. However, it was confirmed that the maximum error was approximately 20% and the burned cell count was not large. Therefore, the results were within the tolerance level.

REFERENCES

Delorme M. An Introduction to Cellular Automata , Kluwer Academic Press, 1999.

Hayashi Y. and Itoigawa E. "Application of spreading simulation model to real urban area and verification of prediction result." Proceeding of the architectural research meetings: materials and construction, structures, fire safety, environmental engineering, Vol.75, 473-476, 2005.

Sato M., Hasegawa I., Yamada S. and Yamana S. "Fire Behavior Analysis for Several Building Uses by Computer Simulation." Summaries of technical papers of Annual Meeting Architectural Institute of Japan. A-2, Fire safety, off-shore engineering and architecture, information systems technology, 113-114, 1999.

Talia D. "Cellular Processing Tools for High-Performance Simulation." Computer, 33(9), ,44-52, 2002.

Wolfram, S. "Cellular Automaton Fluids 1: Basic Theory." Journal of statistical Physics, 45(3), 471-525, 1986

Wolfram S. and Wilhelmson B., High-Speed Computing: Scientific Applications and Algorithm Design, University of Illinois Press, 1998.

Xie M., Sakamoto N, Fujita K. and Ogura H. "An Application of Cellular Automaton to Simulation of Spreads of Fire on a City Site." Vol.35, Research Reports of Fukui National College of Technology, 19-24, 2001.

Xie M., Sakamoto N. and Ogura H. "Application of Cellular Automata to Simulation of the Spread of a Fair on a City Site." Proceedings of the IASTED International Conference on Artificial Intelligence and Applications, 343-347, 2003.

Xie M. and Kiritoshi T. "Improvement of the Model Based on Cellular Automata for Simulating the Spread of Fire." Proceedings of the Sixth IASTED International Conference on Modelling, Simulation and Optimization, , 106-110, 2006.

Xie M. and Okazaki K. "Application of Multi-Agent Systems to Disaster Relief Using Q-Learning." Proceedings of the IASTED International Conference on Software Engineering and Applications, 143-147, 2008.

Yu W. and Saldana R. "Computational Aspects of Modeling Excitable Media Using Cellular Automata." Proceedings of the Second National Workshop and Conference on Modeling, Simulation, and Scientific Computing, 2001.

Yamada A, Takizawa A, Kawamura H. and Tani A. "Simulation of Spreads of Fire on a City Site by Cellular Automata." Architectural Institute of Japan, 657-660, 1998.

Zukoski E., Kubota T. and Cetegan B. "Entrainment in Fire Plume." Fire Safety Journal, Vol.5, 107-121, 1981.

Mengchun Xie was born in Nei Mongol, China. She received her Bachelor's degree in Mechanical Engineering in 1983 and her Master's degree in Mechanical Design from Xi'an University of Technology, China, in 1988, then Ph.D. degree in Information Science from Graduate School of Fukui University, Japan, in 1997. She is now a professor in the Department of Electrical and Computer Engineering at Wakayama National College of Technology.

Dr. Xie research interests include knowledge representation, knowledge processing and modeling in the fields of artificial intelligence, Multi-agent systems and machine learning, modeling and simulation of disaster systems.

In addition, she is a member of both the Information

Processing Society of Japan and International Association of Science and Technology for Development.

Hideyuki Noguchi was born in Osaka, Japan. He received his Assocate's degree in Electrical and Computer Engineering, in 2006 and Bachelor's degree in Mechatronics Engineering Course, Japan in 2008, both from Wakayama National College of Technology. He is now working in Dai Nippon Printing Co., Ltd.